

## CHAPTER 8. MEASUREMENT OF DISCHARGE BY MISCELLANEOUS METHODS

### GENERAL

This chapter deals with the measurement of discharge when conditions are such that it is not feasible to use either a velocity meter or tracer-dilution equipment. The situations and methodologies discussed include the following:

- A. High flow
  - 1. Timed observation of floats
- B. Low flow
  - 1. Volumetric measurement
  - 2. Use of a calibrated portable weir plate
  - 3. Use of a calibrated portable Parshall flume
- C. Unstable flow—roll waves or slug flow
  - 1. Use of photographic techniques

Not discussed here is the practice followed in many countries, other than the U.S.A., in which discharge is measured by observing the head on gaging-station controls that are built in conformity with laboratory-rated weirs or flumes. The transfer of a laboratory discharge rating to a structure in the field requires the existence, and maintenance, of similitude between laboratory model and prototype, not only with regard to the structure, but also with regard to the approach channel. For example, scour and (or) fill in the approach channel will change the head-discharge relation, as will algal growth on the control structure. Both the structure and the approach channel must be kept free from accumulations of debris, sediment, and vegetal growth. Flow conditions downstream from the structure are significant only to the extent that they control the tailwater elevation, which may influence the operation of structures designed for free-flow conditions.

The existence or development of conditions that differ from laboratory conditions will necessitate in place calibration of the control to establish the extent of departure from the laboratory discharge ratings. In place calibration requires the measurement of discharge by current meter or by other means, as described in chapters 5 through 9. Because experience in the U.S.A. has indicated that departure from laboratory conditions is the norm, rather than the exception, gaging-station controls are always calibrated in place by the U.S. Geological Survey.

The reader who is interested in the measurement of discharge by the use of precalibrated controls is referred to publications by the World Meteorological Organization (1971) and the International Standards Organization (1969).

### FLOATS

Floats are seldom used in stream gaging but are useful in an emergency for measuring high discharges under the following circumstances:

1. No conventional or optical current meter is available.
2. A current meter is available but the measurement structure—bridge or cableway—has been destroyed, and equipment for measuring from a boat is unavailable.
3. A conventional current meter is available, but floating ice or drift make it impossible to use the meter.

Surface floats are used in those situations, and they may be almost any distinguishable article that floats, such as wooden disks; bottles partly filled with either water, soil, or stones; or oranges. Floating ice cakes or distinguishable pieces of drift may be used if they are present in the stream.

Two cross sections are selected along a reach of straight channel for a float measurement. The cross sections should be far enough apart so that the time the float takes to pass from one cross section to the other can be measured accurately. A traveltime of at least 20 s is recommended, but a shorter time may be used for streams with such high velocities that it is not possible to find a straight reach of channel having adequate length. The water-surface elevation should be referenced to stakes along the bank at each cross section and at one or more intermediate sites. Those elevations will be used at a later date, when conditions permit, to survey cross sections of the measurement reach, and the end stakes will be used to obtain the length of the reach. The surveyed cross sections will then be used to derive an average cross section for the reach.

In making a float measurement a number of floats are distributed uniformly across the stream width, and the position of each with respect to distance from the bank is noted. The floats should be introduced a short distance upstream from the upstream cross section so that they will be traveling at the speed of the current when they reach the upstream section. A stopwatch is used to time their travel between the end cross sections of the reach. The estimated position of each float with respect to the bank is also noted at the downstream cross section.

If there is no bridge or cableway from which to introduce the floats in the stream, the floats will have to be tossed in from the streambank. If that is the situation that exists at a wide stream, it may be impossible to position any floats in the central core of the stream where most of the flow occurs. A float measurement of discharge made under those conditions would be meaningless. However, the difficulty of introducing floats at intervals across the entire width

of a wide stream can be overcome if a boat can be obtained for the purpose.

The velocity of a float is equal to the distance between the end cross sections divided by the time of travel. The mean velocity in the vertical is equal to the float velocity multiplied by a coefficient whose value is dependent on the shape of the vertical-velocity profile of the stream and on the depth of immersion of the float with respect to stream depth. A coefficient of 0.85 is commonly used to convert the velocity of a surface float to mean velocity in the vertical.

The procedure for computing the discharge is similar to that used in computing the discharge for a conventional current-meter measurement. (See chapter 5.) The discharge in each subsection of the average cross section is computed by multiplying the area of the subsection by the mean vertical velocity for that subsection. The total discharge is equal to the sum of the discharges for all subsections.

Float measurements of discharge that are carefully made under favorable conditions may be accurate to within  $\pm 10$  percent. Wind may adversely affect the accuracy of the computed discharge by its effect on the velocity of the floats. If a nonuniform reach is selected and few floats are used in the cross section, measurement results may be in error by as much as 25 percent.

### VOLUMETRIC MEASUREMENT

The volumetric measurement of discharge is only applicable to small discharges, but it is the most accurate method of measuring such flows. In that method the hydrographer observes the time required to fill a container of known capacity, or the time required to partly fill a calibrated container to a known volume. The only equipment required, other than the calibrated container, is a stopwatch.

The container is calibrated in either of two ways. In the first method, water is added to the container by known increments of volume, and the depth of water in the container is noted after the addition of each increment. In the second method, the empty container is placed on a weighing scales, and its weight is noted. Water is added to the container in increments, and after each addition the total weight of container and water is noted, along with the depth of water in the container. The equation used to determine the volume corresponding to a depth that was read is

$$V = \frac{W_2 - W_1}{w}, \quad (42)$$

where

$V$  = volume of water in container, in cubic feet or cubic meters,

$W_2$  = weight of water and container, in pounds or kilograms,

$W_1$  = weight of empty container, in pounds or kilograms, and  
 $w$  = unit weight of water, 62.4 lb/ft<sup>3</sup> or 1,000 kg/m<sup>3</sup>.

Volumetric measurements are usually made where the flow is concentrated in a narrow stream, or can be so concentrated, so that all the flow may be diverted into a container. Examples of sites presenting the opportunity for volumetric measurement of discharge are a V-notch weir; an artificial control where all the flow is confined to a notch or to a narrow width of catenary-shaped weir crest; and a cross section of natural channel where a temporary earth dam can be built over a pipe of small diameter, through which the entire flow is directed. Sometimes it is necessary to place a trough against the artificial control to carry the water from the control to the calibrated container. If a small temporary dam is built, the stage behind the dam should be allowed to stabilize before the measurement is begun. The measurement is made three or four times to be certain no errors have been made and to be sure the results are consistent.

Volumetric measurements have also been made under particular circumstances when no other type of measurement was feasible. One such circumstance involved a small stream that was in actuality a series of deep pools behind broad-crested weirs that acted as drop structures to dissipate the energy of the stream. At low flows the depth of water on the weir crest was too shallow to be measured by current meter, and the velocity in the pools was too slow for such measurement. To measure the discharge a large container of known volume was placed on a raft held close to the downstream weir face by ropes operated from the banks. A sharp-edged rectangular spout of known width was held so that one end butted tightly against the downstream face of the weir, the base of the spout being held just below the weir crest. The other end of the spout led to the container of known volume. Timed samples of the flow, sufficient to fill the container, were taken at a number of locations along the downstream face of the weir, the raft being moved laterally across the stream, from location to location, by the ropes. The procedure was analogous to making a conventional current-meter discharge measurement. Instead of measuring depth and velocity at a series of observation sites in the cross section, as is done in a current-meter measurement, the discharge per width of spout opening was measured at a series of observation sites. The discharge measured at each site was multiplied by the ratio of subsection width to spout width to obtain the discharge for the subsection. The total discharge of the stream was the summation of the discharges computed for each subsection.

#### PORTABLE WEIR PLATE

A portable weir plate is a useful device for determining discharge

when depths are too shallow and velocities too low for a reliable current-meter measurement of discharge. A 90° V-notch weir is particularly suitable because of its sensitivity at low flows. Three different sizes of weir plate are commonly used by the U.S. Geological Survey; their recommended dimensions are given in figure 129.

The weir plate is made of galvanized sheet iron, using 10- to 16-gauge metal. The 90° V-notch that is cut in the plate is not beveled but is left with flat, even edges. The larger weir plates are made of thinner material than the smaller weir plates, but the medium and large plates are given additional rigidity by being framed with small angle irons fastened to the downstream face. A staff gage, attached to the upstream side of the weir plate with its zero at the elevation of the bottom of the notch, is used to read the head on the weir. The staff gage should be installed far enough from the notch to be outside the region of drawdown of water going through the notch. Drawdown becomes negligible at a distance from the vertex of the notch that is equal to twice the head on the notch. Consequently, if the weir plate has the dimensions recommended in figure 129, the staff gage should be installed near one end of the plate.

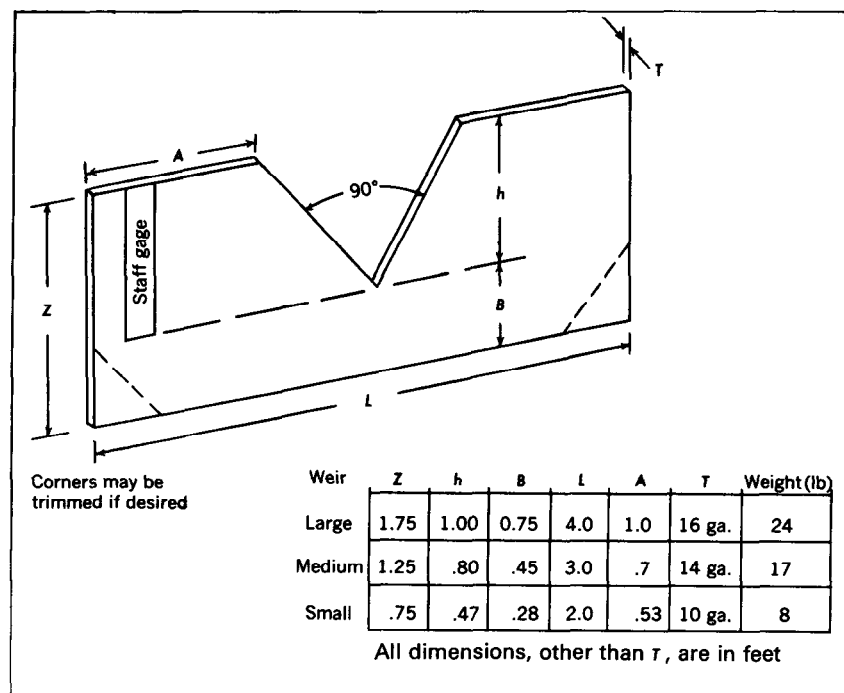


FIGURE 129.—Portable weir-plate sizes.

To install the weir, the weir plate is pushed into the streambed. A pick or shovel may be necessary to remove stones or rocks that prevent even penetration of the plate. A carpenter's level is usually used to insure that the top of the plate is horizontal and that the face of the plate is vertical. Another means of leveling the weir plate is by the use of a staff gage or level bubble attached at each end of the plate. The weir plate is then leveled by adjusting it until both staff gages give identical readings of the water surface or until the level bubbles are centered. Through eyebolts that are attached to the plate, rods are driven into the streambed to maintain the weir in a vertical position. Soil or streambed material is packed around the weir plate to prevent leakage under and around it. Canvas is placed immediately downstream from the weir to prevent undercutting of the bed by the falling jet. It ordinarily requires only one man to make the installation.

A large weir plate of the dimensions shown in figure 129 can measure discharges in the range from 0.02 to 2.0 ft<sup>3</sup>/s (0.00057 to 0.057 m<sup>3</sup>/s) with an accuracy of  $\pm 3$  percent, if the weir is not submerged. A weir is not submerged when there is free circulation of air on all sides of the nappe. The general equation for flow over a sharp-edged 90° V-notch weir is

$$Q = Ch^{5/2}, \quad (43)$$

where

$Q$  = discharge, in cubic feet per second or cubic meters per second,

$h$  = static head above the bottom of the notch, in feet or meters,

and

$C$  = coefficient of discharge.

Each weir should be rated by volumetrically measuring the discharge corresponding to various values of head. In the absence of such a rating, a value of 2.47 may be used for  $C$  in equation 43 when English units are used, or 1.36 when metric units are used.

When the weir is installed it will cause a pool to form on the upstream side of the plate. No readings of head on the notch should be recorded until the pool has risen to a stable elevation. The head should then be read at half-minute intervals for about 3 min, and the mean value of those readings should be the head used in equation 43 to compute discharge. After the completion of the measurement the weir plate is removed.

### PORTABLE PARSHALL FLUME

A portable Parshall flume is another device for determining discharge when depths are too shallow and velocities too low for a current-meter measurement of discharge. The portable flume used by the U.S. Geological Survey is a modified form of the standard Par-

shall flume (p.314–319) having a 3-in (0.076 m) throat. The modification consists, primarily, of the removal of the downstream diverging section of the standard flume. The purpose of the modification is to reduce the weight of the flume and to make it easier to install. Because the portable Parshall flume has no downstream diverging section, it cannot be used for measuring flows when the submergence ratio exceeds 0.6. The submergence ratio is the ratio of the downstream head on the throat to the upstream head on the throat. Although a submergence ratio of 0.6 can be tolerated without affecting the rating of the portable flume, in practice the flume is usually installed so that the flow passing the throat has virtually free fall. That is usually accomplished by building up the streambed a couple of inches under the level converging floor of the flume. (See fig. 130.)

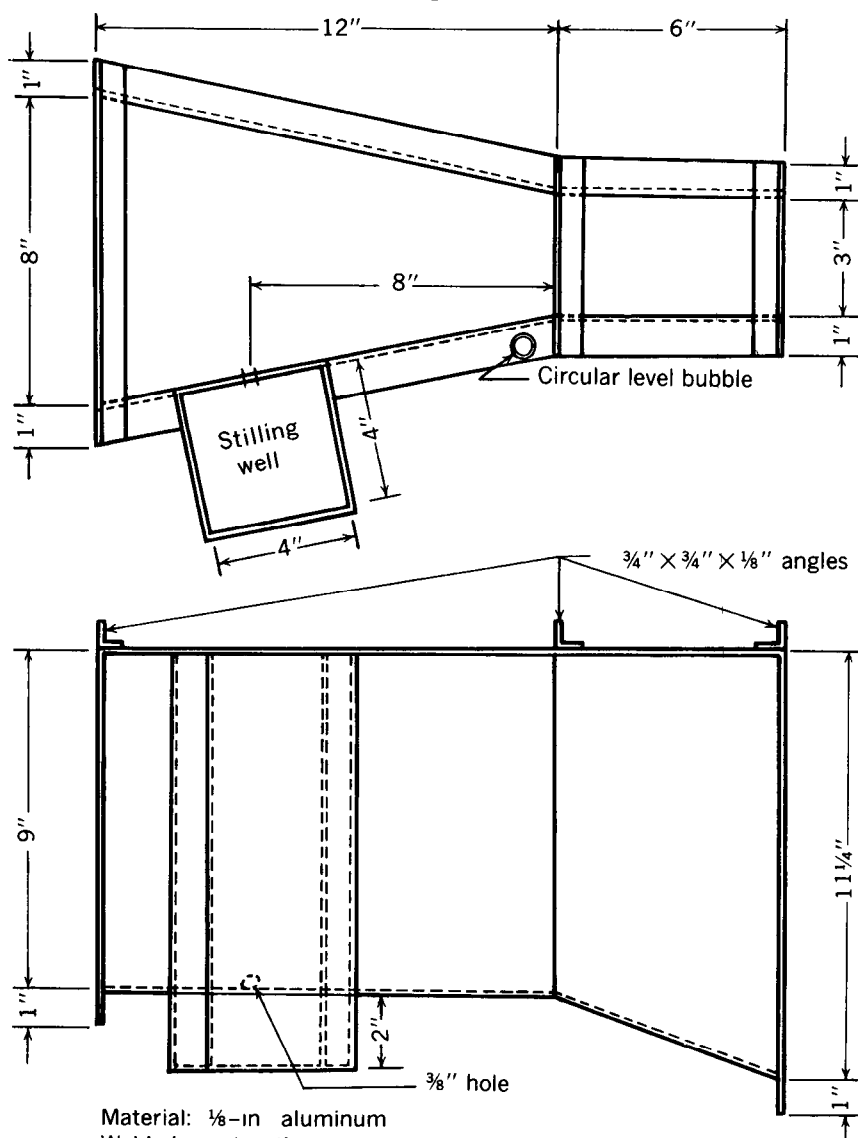
Figure 130 shows the plan and elevation of the portable Parshall flume. The gage height or upstream head on the throat is read in the small stilling well that is hydraulically connected to the flow by a  $\frac{3}{8}$ -in hole. The rating for the flume is given in table 14.

When the flume is installed in the channel, the floor of the converging section is set in a level position by using the level bubble that is attached to one of the braces (fig. 130). A carpenter's level can be used for that purpose if the flume is not equipped with a level bubble. Soil or streambed material is then packed around the flume to prevent leakage under and around it. Figure 131 shows a typical field installation. After the flume is installed, water will pool upstream from structure. No gage-height readings should be recorded until the pool has risen to a stable level. As with the portable weir, after stabilization of the pool level, gage-height readings should be taken at half-

TABLE 14.—*Rating table for 3-in modified Parshall flume*

Gage height (ft)	Discharge (ft <sup>3</sup> /s)	Gage height (ft)	Discharge (ft <sup>3</sup> /s)	Gage height (ft)	Discharge (ft <sup>3</sup> /s)
0.01	0.0008	0.21	0.097	0.41	0.280
.02	.0024	.22	.104	.42	.290
.03	.0045	.23	.111	.43	.301
.04	.0070	.24	.119	.44	.312
.05	.010	.25	.127	.45	.323
.06	.013	.26	.135	.46	.334
.07	.017	.27	.144	.47	.345
.08	.021	.28	.153	.48	.357
.09	.025	.29	.162	.49	.368
.10	.030	.30	.170	.50	.380
.11	.035	.31	.179	.51	.392
.12	.040	.32	.188	.52	.404
.13	.045	.33	.198	.53	.417
.14	.051	.34	.208	.54	.430
.15	.057	.35	.218	.55	.443
.16	.063	.36	.228	.56	.456
.17	.069	.37	.238	.57	.470
.18	.076	.38	.248	.58	.483
.19	.083	.39	.259	.59	.497
.20	.090	.40	.269		

minute intervals for about 3 min. The mean value of those readings is the stage used in table 14 to obtain the discharge. A carefully made measurement should have an accuracy of  $\pm 2$  or 3 percent. After completion of the measurement, the portable flume is removed.



Material:  $\frac{1}{8}$ -in aluminum  
Welded construction

Note: This stilling well can accommodate a 3-in float and be used with a recorder if continuous measurement is desired for a period.

FIGURE 130.—Working drawing of modified 3-in Parshall flume.



## MEASUREMENT OF UNSTABLE FLOW—ROLL WAVES OR SLUG FLOW

### CHARACTERISTICS OF UNSTABLE FLOW

Unstable or pulsating flow often occurs during flash floods in arid areas. In pulsating flow the longitudinal profile is marked by a series of abrupt translatory waves (fig. 132) that rapidly move downstream. Translatory waves, commonly called roll waves or slug flow, can only develop in steep channels of supercritical slope and, therefore, are a matter of concern to the designer of steep-gradient channels. Channels are usually designed for stable flow. Should pulsating flow occur at high stages in a channel so designed, the channel capacity may be inadequate at a discharge much smaller than the design flow. Furthermore, if the overriding translatory wave carries an appreciable part of the total flow, conventional stream-gaging methods cannot be used to determine the discharge. Conventional water-stage recorders



FIGURE 131.—Modified 3-in Parshall flume installed for measuring discharge.

of either the float or pressure-sensing type do not react quickly enough to record the rapidly fluctuating stage; depths and velocities change too rapidly to permit discharge measurement by current meter; no stage-discharge relation exists for pulsating flow; and the commonly used formulas for computing stable open-channel discharge are not applicable.

#### DETERMINATION OF DISCHARGE

In brief, the method of determining the discharge of pulsating flow requires (1) computation of the discharge ( $Q_w$ ) in the overriding waves and (2) computation of the discharge ( $Q_1$ ) in the shallow-depth, or overrun, part of the flow. The sum of the two discharges is the total discharge at the time of observation.

To compute the discharge ( $Q_w$ ) in an overriding wave, which is usually wedge shaped (fig. 132), the dimensions of the wave are observed, and the volume of the wave is divided by the elapsed time between the arrival of waves. For example, if the wedge-shaped wave in a train of waves has a volume of 200 ft<sup>3</sup> (5.67 m<sup>3</sup>) and a wave arrives every 10 s, the discharge in the overriding wave is 200/10, or 20 ft<sup>3</sup>/s (0.57 m<sup>3</sup>/s). Average values are usually used in the computation—for example, the average volumes of five consecutive waves and the average time interval between the arrival of those consecutive waves. It should be mentioned at this point that the longitudinal profile of the wave is actually slightly concave upward and the wave front, while extremely steep, is not vertical. However, to simplify the computation of discharge, the waves are assumed to have a simple wedge shape.

To compute the discharge ( $Q_1$ ) in the shallow-depth, or overrun, part of the flow, the cross-sectional area of the shallow-depth flow is

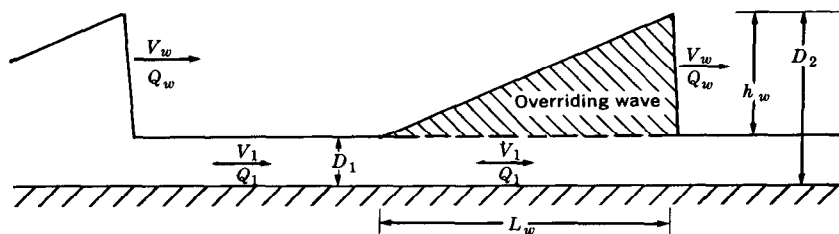


FIGURE 132.—Schematic sketch of longitudinal water-surface profile during pulsating flow.

observed ( $D_1 \times$  channel width), and that area is multiplied by its velocity,  $V_1$ . Seldom will there be time enough between waves to obtain velocity observations of  $V_1$  with a conventional current meter.  $V_1$  may be computed by some stable-flow equation, such as the Manning equation, but preferably the surface velocity of shallow-depth flow should be measured by optical current meter. (See p. 91–93.) The surface velocity can then be multiplied by an appropriate coefficient—0.9 or 0.85, for example—to give the mean velocity,  $V_1$ . The final step is to compute the total discharge at the time of observation by adding  $Q_w$  and  $Q_1$ .

#### EXAMPLES OF DISCHARGE DETERMINATION

This section briefly describes two examples of discharge determinations made under conditions of pulsating flow in southern California.

Holmes (1936) obtained photographic documentation of a train of transitory waves in a steep stormflow channel. The rectangular channel was 43 ft (13.10 m) wide, 8 ft (2.44 m) high, and had a slope of 0.02. The waves themselves lapped at the top of the manmade channel giving them a height ( $D_2$ ) of 8 ft, and their length ( $L_w$ ) was about 600 ft (180 m). The average distance between wave crests was about 1,200 ft (360 m), and the average time interval between arrival of the waves ( $T_p$ ) was 51 s. The channel between waves was dry or nearly so ( $D_1=0$ ), meaning that the entire discharge was transported in the waves. The average discharge over the time  $T_p$ , computed from the equation

$$Q = (\text{volume})/T_p = \frac{1}{2} (W) (h_w) (L_w)/(T_p), \quad (44)$$

was therefore about 2,000 ft<sup>3</sup>/s (56 m<sup>3</sup>/s). The channel had been designed for stable-flow conditions and, according to the Manning equation, had a capacity of about 16,000 ft<sup>3</sup>/s (405 m<sup>3</sup>/s). We see then, that under the observed conditions of unstable flow the channel could accommodate only one-eighth of the design discharge.

Thompson (1968) described the experimental measurement of pulsating flow in the rectangular stormflow channel of Santa Anita Wash in Arcadia, California. The concrete channel was 28 ft (8.5 m) wide and had a slope of 0.0251. On the infrequent occasions when the channel had carried storm runoff in the past, the flow had been observed to be pulsating. For the test, water was released into the channel from an upstream reservoir at controlled rates of approximately 100 ft<sup>3</sup>/s (2.8 m<sup>3</sup>/s), 200 ft<sup>3</sup>/s (5.6 m<sup>3</sup>/s), 300 ft<sup>3</sup>/s (8.5 m<sup>3</sup>/s). Unstable flow did not develop until the flow came out of a bend in the steep storm channel and entered a straight reach of the channel. In other words, the released flow was stable upstream from the bend and pulsating downstream from the bend. During the release of water, dis-

charge measurements were made continuously by current meter in the stable flow upstream from the bend. The discharge hydrograph based on those measurements is shown by solid line in figure 133. Downstream from the bend a simultaneous attempt was made to measure the unstable flow by the method described in this paper, for the purpose of verifying the method.

At the test site, about 3,300 ft (1,000 m) downstream from the bend, the equivalent of a series of staff gages, in the form of a grid, was painted on one of the vertical channel walls so that water-surface

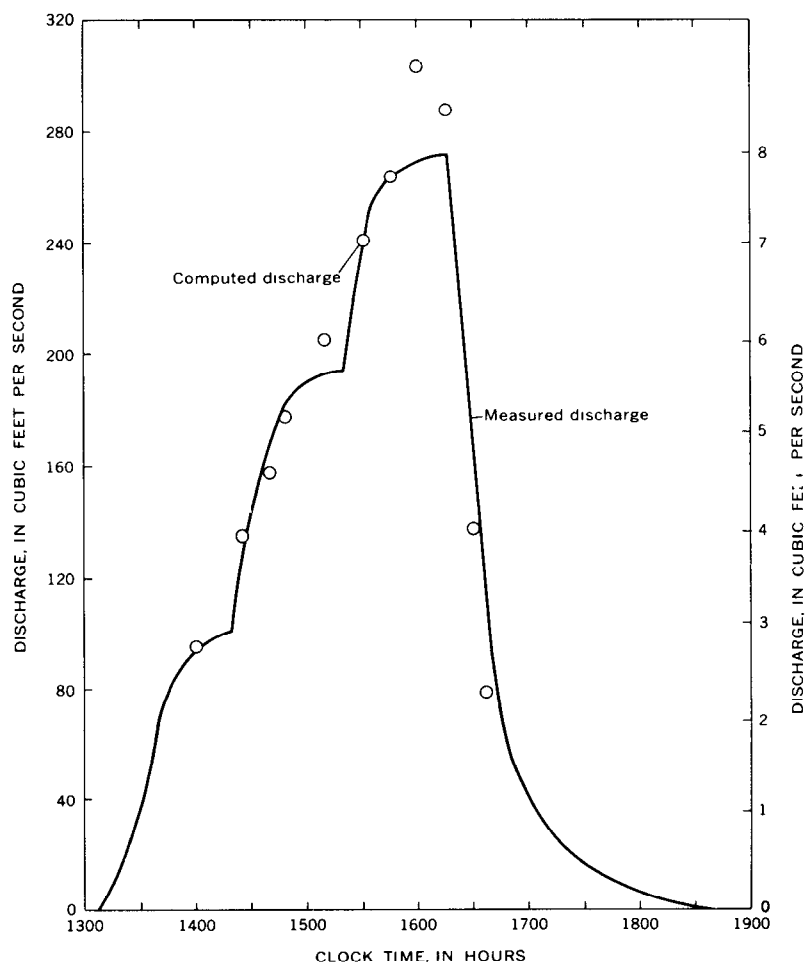


FIGURE 133.—Discharge hydrograph at Santa Anita Wash above Sierra Madre Wash, Calif., April 16, 1965, and plot of discharges computed from observations of flow.

elevations could easily be read by a crew of observers. Some of the observers were equipped with both still- and motion-picture cameras to document the observations; others were equipped with stopwatches to time wave velocity over a measured course of 102 ft (31 m) and to obtain the elapsed time between the arrival of waves. The waves were not evenly spaced and occasionally one wave would overtake another, but in general the waves were fairly uniform in size, maintained their spacing, and underwent little attenuation in the 3,300-ft reach above the test site. For computation purposes the average volumes of five consecutive waves and their average elapsed time between arrivals ( $T_p$ ) were used, and discharges were computed at 15 min intervals using the procedure described earlier. For example, at the time of greatest discharge, the average value of  $T_p$  was 9.6 s, and the average wave dimensions were  $D_1 = 0.42$  ft (0.13 m),  $h_w = 0.66$  ft (0.20 m), and  $L_w = 158$  ft (48.2 m). The computed value of  $Q_w$  equaled 152 ft<sup>3</sup>/s (4.30 m<sup>3</sup>/s). No optical current meter was available at the time, and  $Q_1$  was therefore computed by the Manning equation. The computed value of  $Q_1$  also equaled 152 ft<sup>3</sup>/s (4.30 m<sup>3</sup>/s), giving a computed total discharge 304 ft<sup>3</sup>/s (8.60 m<sup>3</sup>/s) at the time of observation. The values of discharge that were computed at 15-min intervals are plotted as open circles in figure 133 and show satisfactory agreement with the "true" discharge hydrograph. The field test of the method was therefore considered a success.

#### PROPOSED INSTRUMENTATION

There is as yet no instrumentation that is operational for automatically recording the data required to compute discharge under conditions of pulsating flow. Thompson concluded the above-cited report (1968) by describing three types of automatic instrumentation—photographic, depth sensing, and dye dilution—that might be developed for that purpose.

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